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Spatial externalities of technological innovation and economic growth

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Introduction

The motivation for this study was a monograph by the British economist Diana Coyle. There the author concludes that the underestimation of economic growth, traditionally performed on the basis of GDP: the modern economy is less tangible and easy to measure through GDP, it measures production, but does not serve to measure the welfare of the nation. In this paper, the attention is drawn to open questions of regional economic growth measurement. First, using gross regional product (in macroeconomics – GDP), it is difficult to assess the growth in the quality of goods, services and productivity in the economy, manifested in innovation [Coyle, 2014]. Second, interregional interactions can be an external determinant of the knowledge life cycle (in particular, technological innovations) in the modern digital economy, increasing the convergence of their growth rates. The failure to include a spatial lag in the model, as in the general case of missing essential variables, leads to a bias in the estimates of the explanatory factors [Kolomak, 2010; Demidova, Ivanov, 2016].

The main objective of the paper is to compare the speed of β-convergence, short-term spatial externalities (effects) of annual growth rates of technological innovations and gross regional product for empirical testing of theoretical conclusions, reflected in [Coyle, 2014]. Check whether we get the same conclusions about the growth of the economy, measuring the GRP and measuring innovation? Check whether the regions aspire to the same or to their own sustainable state?

The choice of static spatial models is determined by the interest in the dynamics of short-term (annual) spatial effects from cross-sectional data. The use of unconditional and conditional β-convergence specifications makes it possible to determine whether the regions are striving for the same steady state or whether the growth rates in each region are decreasing as they approach their own steady state. The study relies heavily on the works of [Balash 2012, Scherngell et al., 2014, Demidova, Ivanov, 2016].

The theoretical basis of empirical studies of spatial effects of knowledge determinants of economic growth are based in the works of [Solow, 1957; Machlup, 1962; Griliches, 1979, Krugman, 1991]. Evaluation of spatial econometric models on the example of the us, European and Chinese economies shows the impact of interregional knowledge capital flows on the overall factor productivity in the region (TFP) [Robbins, 2006; Fischer et al. In 2009; Kuo & Yang, 2008; Scherngell, Borowiecki, Y. Hu, 2014]. In the work of [Barro, 1990] introduced the term β-convergence of economic growth as a negative dependence of growth rates on the initial level of development: poor regions have higher rates of economic growth than the rich, which in the long term should lead to the alignment of regional levels of economic development. The paper [Barro, 2004] reviews the results of β-convergence estimates in different countries of the world.

The influence of knowledge and spatial dependence on economic growth in more developed countries, as opposed to less developed ones, is shown in [Guastella, Timpano, 2016]. Evaluation of determinants of economic growth in the aspect of inter-country and intra-country convergence, taking into account spatial effects performed in [Cuaresma et al., 2014].

The review of spatial models of economic growth convergence in Russian regions [Gafarova, 2017] shows a low degree of spatial econometrics methods approbation. Proofs of spatial externalities for regional economic growth rates on the example of SLM, SEM, SAC, SDM models are shown in [Kolomak, 2010; Balash,2012]. The article [Demidova, Ivanov, 2016] shows a violation of the assumption about the identity of the spatial autocorrelation coefficient for all regions and concludes that it is necessary to take into account the heterogeneity of the regions under the conditions for interaction with other regions. The regional economic growth from the position of convergence of growth rates of the capital of knowledge, an assessment of short-term interregional externalities of knowledge in domestic scientific literature is practically not investigated. The use of static spatio-econometric models of unconditional and conditional β-convergence of growth rates of technological innovations and economic growth in the context of measuring the modern digital economy in the regions is the novelty of the work.

Main hypotheses, data and models

According to [Barro, Sala-i-Martin, 1992; Kolomak, 2010; Balash, 2012; Scherngell, Borowiecki, Y.Hu, 2014; Demidova, Ivanov, 2016], the indicator of gross regional product per capita per year, in million rubles was used to measure economic growth. The issue of choosing a knowledge capital meter by science has not been solved: the share of PhD and hired engineers in the number of employed in the industry [Robbins, 2006], the number of corporate patent applications [Fischer et al., 2009, Scherngell, Borowiecki, Y. Hu, 2014]. Scientifically recognized interest in innovation and technology transfer for sustainable macroeconomic growth [Romer, 2010; Bloom , Romer et al., 2013; Schwab et al., 2018], technological structure of the Russian economy ["GOST R 54877-2016. Knowledge Management. Guidance for personnel in working with knowledge. Measurement of knowledge"] allows us to intuitively assume that technological innovation plays a leading role in the measurement of knowledge capital in the domestic economy. Therefore, the paper uses the indicator of growth in the cost of technological innovations per capita, in million rubles. The logarithms of the basic annual growth rates relative to the 2010 level for the selected indicators are dependent variables.

To take into account the influence of each region in this study, the boundary weighing matrix obtained on the basis of the database on the location of administrative boundaries – GADM – was used. To eliminate the bias in the model of conditional β-convergence, factor control variables of matrix X, characterizing regional stable growth trajectories of the base year 2010, are included: economic development of the region (volume of investments in fixed capital per capita, rubles), reserve of human capital (number of University students, thousand people).; number of granted patents for inventions, pcs.), development of the Internet (use of the Internet in organizations, %)[Demidova, Ivanov, 2016; Lugovoy,2007; Kolomak, 2010; Balash, 2012].

Global Moran indixes were determined to reveal the spatial dependence [Anselin, 1995; Demidova, Ivanov, 2016]:

$$I(X) = \frac{N}{\sum_{i,j} w_{ij}} \cdot \frac{\sum_{i,j} w_{ij}(X_i - \bar{X})(X_j - \bar{X})}{\sum_i (X_i - \bar{X})^2},$$

where N – number of regions, X – the logarithm of expenditure on technological innovation growth rate per capita, the logarithm of GRP growth rate per capita, w_{ij} - weight boundary matrix elements.

To identify the spatial clustering of regions, local Moran indices were determined (LISA – Local Index Spatial Autocorrelation) [Anselin, 1995]:

$$I_{Li} = N \cdot \frac{(\mathrm{X}_i - \bar{X})\sum_i w_{ij}(\mathrm{X}_j - \bar{X})}{\sum_i (\mathrm{X}_i - \bar{X})^2}$$

By the method of maximum likelihood in the R environment according to the anthology "Regions of Russia. Socio-economic indicators. 2017." the static spatio-econometric models with the spatial lag of the dependent variable, errors, regressors or lag combinations Linear regression model without spatial effects (OLS), Spatial lag model (SLM), Spatial Error model (SEM), Spatial Durbin model (SDM), Spatial Durbin Error model (SDEM), Model with spatial autoregressive lag and spatial interaction in errors (SAC), Models with spatial lags of independent variables (SLX), General nesting spatial model (GNS) [Anselin, 1988; LeSage, Pace, 2009] unconditional and conditional β-convergence for two dependent variables were estimated: the logarithm of expenditure on technological innovation growth rate per capita, the logarithm of GRP growth rate per capita.

The article also defines indirect limiting effects [LeSage, Pace, 2009]:

$$M(X_r)_{indirect} = M(X_r)_{total} - M(X_r)_{direct},$$

$$M(X_r)_{total} = \frac{1}{N} i_N{}' S_r(W) i_N,$$

$$M(X_r)_{direct} = \frac{1}{N} tr(S_r(W)),$$

$$S_r(\mathrm{W}) = (\mathrm{I_n} - \rho \mathrm{W})^{-1} \beta_{\mathrm{r}},$$

$$\hat{\beta}_{\mathrm{r}} = \partial \mathrm{y} / \partial \mathrm{X_r}$$

where M(Xr)total - total marginal effect, M(Xr)direct – direct marginal effect, M(Xr)indirect – indirect marginal effect, N – number of observations, Sr(W) – higher order weighing matrix, I_n – n-dimensional identity matrix, ρ – spatial autoregression coefficient, β - regression coefficient for Xr, r- independent variable number, tr(Sr(W)) - matrix trace Sr(W).

Based on [Romer, 1990; Coyle, 1998; Barro, 2004] and the purpose of the paper to test, two main hypotheses are formulated:

H1: the speed of β-convergence of technological innovation growth rates in the modern economy is higher than the speed of β-convergence of economic growth rates

H2: short-term spatial externalities of technological innovation growth rates and spatial externalities of economic growth have different effects on β-convergence processes

To test the hypothesis H1 the comparison of the coefficients of β-convergence and speed of convergence in the models was made for the different dependent variables. The convergence rate shows how many fractions of a unit the gap between regions is reduced by in a single period of time. It has a sign opposite to the coefficient β, that is, if the latter is negative, the speed is greater than zero.

To test hypothesis H2 after the selection of models [Elhorst, 2014] the comparison of spatial externalities "other region - given region" was made on the basis of spatial auto-regressive ρ coefficients, and comparison of spatial externalities “given region – other region" on the basis of indirect marginal effects. The autoregression coefficient ρ at the spatial lag of the dependent variable allows to reveal the influence of GRP growth rates per capita (or growth rates of expenditures on technological innovations) of other regions on the studied indicator of this region. The insignificance of the spatial autoregressive coefficient means that the processes of economic growth (or growth of technological innovations) in different regions are not interconnected, a positive value indicates the cooperation of regions, and a negative value indicates the competition of regions. Indirect limit effects show how a change in the baseline of a given region can affect changes in the dependent variable in other regions.

In the spatial-econometric models of β-convergence under the assumption of the same dimension of different dependent variables by taking the logarithm of growth rate, the conclusion on statistically significant difference of the spatial autoregressive coefficients is suggested to formulate on the basis of bounds unit values of confidence intervals comparison: if the intervals overlap, there is no statistical difference between the coefficients.

Empirical results

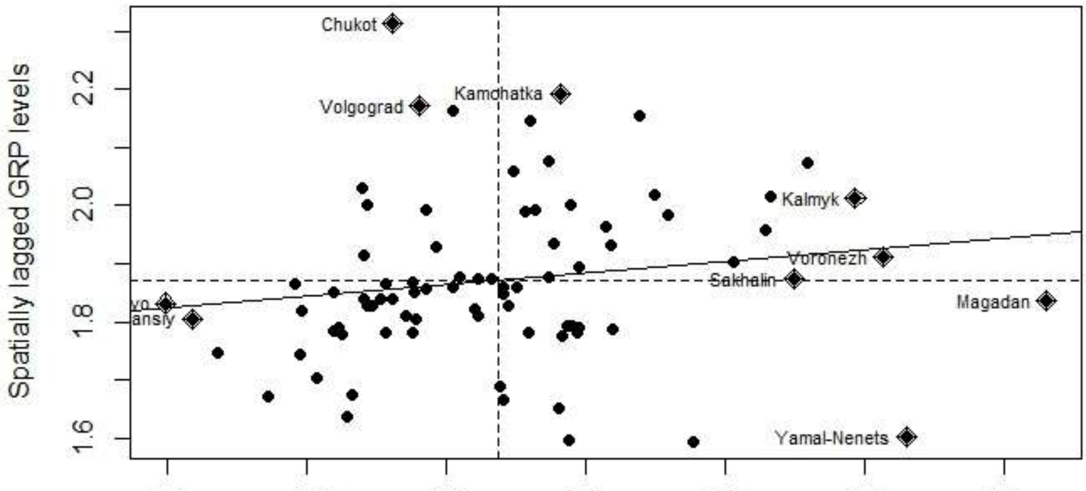
Global Moran indixes (table 1) confirm the need to take into account the β-convergence modes of spatial effects, which is consistent with the results in the works [Balash, 2012; Demidova, Ivanov, 2016].

Table 1 – The global Moran's I

Indicator	2011	2012	2013	2014	2015	2016
GRP per capita growth rate	0,027	-0,008	0,159**	0,225***	0,132**	0,098*
Expenditure on technological innovation per capita growth rate	0,069	0,136**	0,129**	0,152**	0,234***	0,220***

Note: ***, **, * – significance at the level of 1, 5, and 10%, respectively.

In 2016 (Fig.1) in the HH quadrant of the Moran diagram there are Kalmykia, Voronezh region, Sakhalin region with high growth rates of GRP per capita among the same neighbors, relatively high growth rates of costs of technological innovations per capita among the same neighbors are especially characteristic for the Khanty-Mansiysk Autonomous district, Tyumen, Omsk, Tomsk regions.



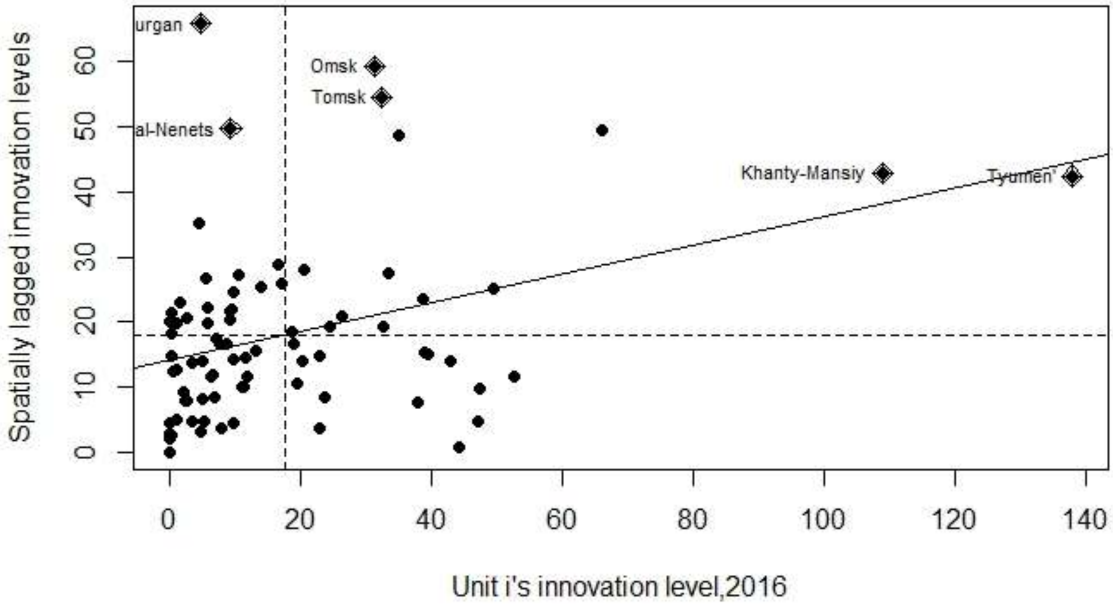


Fig.1. Moran charts the growth rate of GRP per capita and growth rate of expenditures for technological innovation per capita in 2016

In the HL quadrant, the Magadan region and Yamal-Nenets Autonomous Region are distinguished with relatively high growth rates of GRP per capita among neighbors with low growth rates of GRP per capita. The relatively low growth rates of per capita expenditures on technological innovations among neighbors with high growth rates of expenditures (LH square) are typical for Yamal-Nenets Autonomous district and Kurgan region.

The Moran scatterplots from 2011 to 2016 reflect the positive spatial correlation of the regions in terms of per capita GRP growth rates, with the increase in spatial clustering in 2013-2014, and also the positive spatial correlation of the regions in terms of the growth rate of costs of technological innovations per capita, which was clearly manifested in 2015-2016 (Fig. 1P, Fig. 2P of Application).

Local Moran indexes (LISA) to detect local clustering regions in terms of GRP growth rate per capita is North Caucasus regions – Chechnya, Dagestan, Ingushetia, North Ossetia and nearby Kalmykia and the Astrakhan region; Eastern Siberia, Irkutsk region, Krasnoyarsk territory, Republic of Tuva; West Siberia - the Tyumen region, Khanty-Mansi Autonomous region; Far East - Trans-Baikal territory, Amur region, Buryatia, the Jewish Autonomous region; the South-Western and Central part of Russia - Belgorod, Orel, Voronezh region; in terms of growth rates of costs for technological innovations per capita are the regions of the North Caucasus – the Chechen Republic and North Ossetia; Western Siberia – Tyumen region, Omsk region, Khanty-Mansiysk Autonomous district, Yamalo-Nenets Autonomous district; Eastern Siberia - Krasnoyarsk territory.

The convergence of the levels of development of regions in terms of GRP per capita in 2013, 2014 confirm a statistically significant negative convergence coefficient β and the result of LR-test in models such as SLM, SEM, SDEM, SAC unconditional β-convergence, whereas in 2015, 2016 unconditional β-convergence was not statistically confirmed. All specifications of spatial models of conditional β-convergence confirmed the convergence of economic growth rates in the regions in 2013 -2016, consistent with the results [Balash, 2012; Demidova, Ivanov, 2016]. There was a slowdown in the speed of β-convergence of economic growth (table 2) and the increase in the time to overcome half the distance separating the economy of the region from the balance.

Table 2 – The speed and time of β-convergence of economic growth rates

Models and specifications	2013	2014	2015	2016
SAC – speed of β-convergence , in fractions of pc	0,13737	0,135581	0,094001	0,090387
SAC – time of β-convergence , in years	5,04585	5,11242	7,37385	7,66863
GNS – speed of β-convergence , in fractions of pc	0,407925	0,328431	0,238784	0,215331
GNS – time of β-convergence , in years	1,69920	2,11048	2,90281	3,21899

The discrepancy (β-divergence) of the regions in the growth rates of costs of technological innovations per capita was confirmed in all the specifications of spatio-econometric models for 2013-2016 by a statistically significant positive convergence coefficient β and the result of the LR test. Thus, it is not possible to determine the speed of β-convergence and test the H1 hypothesis.

Modular values of confidence interval boundaries for statistically significant spatial autoregressive coefficient ρ (table 3) the studied dependent variables in the SAC and GNS models of unconditional β-convergence for 2015 and 2016 and in the SAC models of conditional β-convergence for 2015 intersect. Under the assumption of equal dimensionality of the dependent variables in the direction of "other region – given region" statistical differences between the effect of positive spatial externalities of the technological innovation growth. On our case cooperation of regions on dismissing of its rates and negative spatial externalities on economic growth (in our case competition of regions) on β-convergence rates.

Table 3 - The confidence intervals of the spatial autoregression coefficient in 2015 and 2016

Models	GRP per capita growth rate	The growth rate of expenditure on technological technological innovation per capita
Unconditional β-convergence models		

SAC, 2015	[0,1915**; 0,9680**]	[0,1598**; 0,6322**]
SAC, 2016	[-1,1312*; -0,0360*]	[0,4007***; 0,7583***]
GNS, 2015	[0,1777**; 0,9783**]	[0,1683**; 1,0387**]
GNS, 2016	[-1,1191**;-0,0744**]	[0,4284***; 0,9253***]
Conditional β-convergence models		
SAC, 2015	[-1,0009*; -0,0617*]	[0,2097***; 0,6491***]
SAC, 2016	[-1,004*; -0,0987*]	[0,4698***; 0,7677***]
GNS, 2015	[-1,0176; 0,0726]	[0,2884**; 0,9479**]
GNS, 2016	[-0,9904;0,1438]	[0,4345***; 0,8746***]

Modular values of confidence intervals boundaries of indirect limiting effects for the studied dependent variables (table 4) unconditional β-convergence models do not intersect. According to the SAC model, the basic level of spending on technological innovation per capita has had a positive impact on the growth rate of this indicator in other regions. The model of conditional β-convergence of the SAC type in 2015 for the basic levels of variables showed statistically different confidence intervals in the direction of "given region – other region", while the influence of the basic level of technological innovations of this region on the growth rates of technological innovations in other regions prevails over the influence of the basic level of GRP per capita on the economic growth rates in other regions in the processes of β-convergence. In 2016, there is an intersection of confidence intervals of indirect limiting effects: there are no statistical differences. The hypothesis of H2 on the different effects of spatial externalities of the studied dependent variables was partially confirmed by empirical evidence.

Table 4 – Confidence intervals of indirect marginal effects in β-convergence models in 2015 and 2016

Models and Variables	GRP per capita growth rate				The growth rate of expenditure on technological technological innovation per capita			
	Unconditional β-convergence		Conditional β-convergence		Unconditional β-convergence		Conditional β-convergence	
	I_L	I_U	I_L	I_U	I_L	I_U	I_L	I_U

SAC, 2015								
grp_ln	-0.16	0.01	7,7e-03**	9,8e-02**				
innov_ln					0.20*	1.10**	0,24***	1,14***
invest			-6,6e-07**	-5,7e-08**			0,00	0,00
stud			-1,9e-04*	-9,1e-06*			0,00	0,00
inter			0,00	0,00			-0,02	0,03
pat			0,00	0,00			0,00	0,00
SAC, 2016								
grp_ln	-0.01	0.06	0,01**	9,24**				
innov_ln					0.54***	1.59***	0,51**	1,30**
invest			-7,0e-07**	-9,8e-08**			1,2e-06**	8,1e-06**
stud			-2,0e-04**	-2,0e-05**			8,4e-04*	7,2e-03*
inter			0,00	0,00			-0,03	0,04
pat			0,00	0,00			0,00	0,00
GNS, 2015								
grp_ln	-1.13	0.68	-0,41	1,06				
innov_ln					0.03	1.25	-0,28	0,67
invest			-1,76**	-0,14**			-0,43	1,03
stud			-0,85**	-0,01**			0,03	1,65
inter			-0,57	0,07			-0,07	1,04
pat			-0,63	1,43			-0,55	2,87
GNS, 2016								
grp_ln	-0.19	0.83	-0,19	1,32				
innov_ln					0.26	1.54	0,10**	1,01**
invest			-1,92**	-0,20**			-0,67	0,69
stud			-1,03**	-0,16**			-0,07	1,15
inter			-0,54	0,16			-0,26	0,80
pat			-0,55	1,55			-0,10	3,17

Note: grp_ln - logarithm of GRP per capita in 2010, innov_ln - logarithm of the level of costs of technological innovations per capita in 2010, invest - the volume of investment in fixed capital per capita, rubles, stud - the number of University students, thousand people, inter - the use of the Internet in organizations, %, pat - the number of granted patents for inventions, pcs.

The influence of the control variable "the use of the Internet in organizations" and, unlike [Fischer et al., 2009; Scherngell et al., 2014], the control variable "the number of patents granted for inventions" on dependent variable was not confirmed. In contrast to [Demidova, Ivanov, 2016], a positive relationship of the variable "the investments volume in fixed capital per capita, in rubles." with the rate of economic growth in most models of conditional β-convergence from 2013 to 2016 was determined, the growth rate of technological innovation in GNS models of conditional β-convergence for 2015, 2016, consistent with the results of the study [Balash, 2012]. In most of the constructed models, the coefficients for the spatial lags of the control variables of the matrix X were insignificant. In contrast to the results in [Scherngell et al., 2014], no statistically significant indirect limiting effects were found for the variable "number of granted patents for inventions, pcs.", "Internet use in organizations, %" on the studied dependent variables. Conditional β-convergence models revealed statistically significant indirect limiting effects for the variables "volume of investments in fixed capital per capita, in rubles" and "number of University students, in thousand people": negative impact on convergence in GRP growth rates in other regions (SAC for 2015,GNS for 2015 and 2016) and positive impact on growth rates of technological innovations in other regions.

Conclusions

Positive spatial autocorrelation is increasing and spatial effects need to be taken into account in econometric studies of the growth rates of the modern digital economy in the Russian regions, consistent with [Balash, 2012; Demidova, Ivanov, 2016]. The speed of β-convergence of economic growth in the regions is slowing down, there is a process of β-divergence of costs growth rates for technological innovations in the regions. In the direction of "other region – given region" statistical differences between the effect of positive spatial externalities of the technological innovation growth (cooperation of regions) on the β-divergence of its rates and economic growth negative spatial externalities (competition of regions) on its β-convergence rates. In the direction "given region – other region" statistically different predominance of spatial externalities of technological innovations costs over economic growth externalities was found. Thus, the conclusion [Coyle, 2014] about the impossibility of unambiguously assessing productivity growth in the modern economy, manifested in innovation, based on the measurement of GDP, is confirmed. The positive relationship of the variable "volume of investments in fixed capital per capita, rubles" with the rate of economic growth in most models of conditional β-convergence from 2013 to 2016, as well as the rate of growth of technological innovation costs in the GNS models of conditional β-convergence for 2015, 2016, which is consistent with [Balash, 2012]. For the variable "Internet usage in organizations, in percent" connection was not confirmed and, unlike Fischer , Scherngell et al., for the variable "number of granted patents for inventions, pcs." with the rate of economic growth and the rate of growth in the cost of technological innovation was not confirmed either. The ambiguity of the results in the regressions of unconditional and conditional β-convergence of growth rates in the regions is shown, which is consistent with [Glushchenko, 2010; Kolomak, 2014]. Finally, the ambiguity of short-term spatial externalities from cross-sectional data for Russian regions due to small samples, previously obtained in [Demidova, 2014], speaks in favor of identifying long-term spatial externalities on panel data analysis models.

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